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Geologic Discussion of the Borealis Gold Deposit, Mineral County, Nevada

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INTRODUCTION

Borealis is a volcanic-hosted disseminated gold deposit in west-central Nevada, 160 km southeast of Reno (fig. 53). The mine is owned and operated by Tenneco Minerals Inc. The descriptions and concepts presented herein pertain only to the original Borealis ore body and stem from my experience as project geologist during mine development, early production, and district-exploration stages from May 1980 to March 1983.

The stratigraphic, structural, and mineralogic characteristics of the Borealis deposit resemble those in several classic western Nevada and eastern California precious-metal districts, including the Comstock, Aurora, Bodie, Masonic, Tonopah, and Goldfield. All of these districts contain disseminated, vein, and (or) stockwork deposits of Miocene-Pliocene age in volcanic or associated sedimentary rocks. The Borealis deposit contains evidence of fossil geothermal activity, somewhat comparable to the McLaughlin deposit in California, the Hasbrouck Peak and Round Mountain deposits and Steamboat Springs in Nevada, and the DeLamar deposit in Idaho.

The purpose of this chapter is to discuss the regional setting of Borealis, describe the general characteristics of the Borealis ore types, and suggest a genetic model for the deposit.

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REGIONAL GEOLOGY

The Borealis deposit occurs near the west margin of the Basin and Range province on the east edge of

Fletcher Valley, one of the structural basins in the region (Gilbert and Reynolds, 1973). Mesozoic basement rocks include granitic, metavolcanic, and metasedimentary rocks, overlain unconformably by thick sections of Cenozoic sedimentary and volcanic rocks. The Wassuk Range, forming the east side of Fletcher Valley, is composed of several granitic plutons that range in age from Late Jurassic into Cretaceous. The west flanks of this range are covered by Tertiary andesite and related rocks of intermediate composition, and include laharic breccias and minor lava flows (Stewart and others, 1982). These deposits, in turn, are overlain by Quaternary basalt flows, locally including cinder cones and the Aurora Crater, about 13 km southeast of Borealis. Fletcher Valley is filled with Quaternary alluvial-fan and pediment deposits. The Miocene and Pliocene volcanic and sedimentary rocks exposed along the margins of the basin are locally silicified and form bold outcrops. The uppermost parts of the Borealis breccias and sinters occur in one of these siliceous outcrops along the southeastern quadrant of the basin.

North-south- and northwest-trending steep normal faults, which may have displacements of 1,800 to 3,000 m, have created sharply defined ranges and valleys, such as the Wassuk Range and Fletcher Valley (Gilbert and Reynolds, 1973). This region also lies within the broad northwest-trending Walker Lane shear zone (Shawe, 1965), which is cut by northeast-trending faults (Gilbert and Reynolds, 1973).

Most ore deposits in the western part of the Basin and Range province are associated with complex uplift and doming, the result of the introduction of intrusive bodies (Silberman and others, 1976). Andesite is the predominant host rock for precious-metal deposition in this area; most of the gold produced in Nevada came

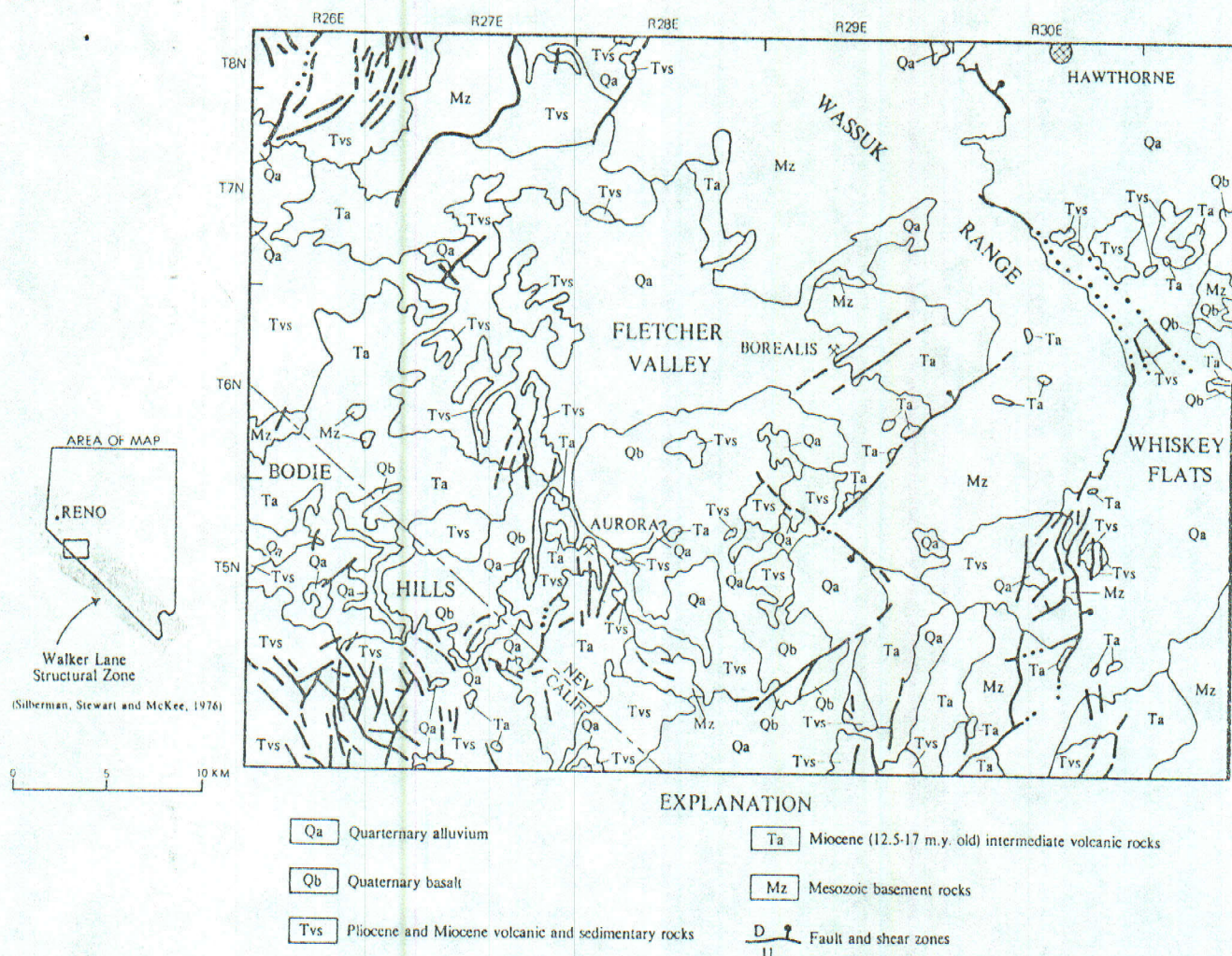


Figure 53. Geologic map of the Fletcher Valley area, Nev. (after Carlson and others, 1978).

from Cenozoic deposits along the Walker Lane zone (Silberman and others, 1976).

The western part of the Basin and Range province in Nevada contains numerous associated warm or hot springs (Stearns and others, 1937, p. 91-93). Many of the modern hot springs are situated along known normal faults, and there also is evidence of fossil hot-spring activity along these structures. The Borealis area has had a long history of magmatic volcanic activity from the Paleozoic through the Quaternary (Stewart and others, 1982; Silberman and others, 1976), which provides an extended source of heat for hydrothermal activity in the region. The deep faults promoted circulation of meteoric water to deep levels, where rock temperatures were elevated because of magmas.

MINE GEOLOGY

Stratigraphy

Stratigraphic units at Borealis include sedimentary- and volcanic-rock types, both of which host gold mineralization. The timespan represented by these units extends from prehydrothermal through posthydrothermal activity. Thus, some units in the stratigraphic section were deposited contemporaneously

with hydrothermal activity and, as such, were altered either during or immediately after deposition. In addition, some units were actually formed by the hydrothermal system itself.

The oldest rocks at Borealis are Miocene hornblende andesite flows and laharic breccias. Tuffaceous sedimentary rocks are interbedded with the andesitic units; the sedimentary layers range from 1.5 to 15 m in thickness. The complete Miocene volcanic section is at least 450 m thick, possibly as thick as 900 m. This section of Miocene volcanic rocks and interbedded tuffaceous sedimentary rocks is equivalent to unit Ta₂ of Stewart and others (1982), which occurs throughout the Walker Lake 1°x2° sheet (fig. 53).

The Miocene andesitic section is unconformably overlain by a sequence of Pliocene rocks that host the Borealis deposit. The Pliocene rocks are divided into three units: (1) spring-vent deposits, (2) quartz breccia, and (3) talus deposits. Units 1 and 2 were formed by geothermal activity, whereas unit 3 was simply deposited over and around the active Pliocene geothermal system that was also responsible for gold deposition at Borealis.

The spring-vent deposits constitute a bleached unit that is varying silicified and argillized. It probably identifies an area near fossil geothermal vents of the Borealis hydrothermal system and is the earliest

geothermal deposit formed by the system. This unit is defined by strong bleaching, argillization, and silicification within Miocene andesite and Pliocene tuffaceous sedimentary rocks. The unit crops out at the present topographic surface and extends to depth, crosscutting the earlier andesitic section. Mineral assemblages that define the spring-vent deposits include opal-cristobalite and kaolinite-alunite. Oxides and sulfides occur in sparse amounts in both assemblages.

The quartz breccia unit was deposited unconformably over the spring-vent unit. The external geometry of the quartz breccia unit is broadly lenticular and shares a sharp contact with the underlying spring-vent deposits and the older andesitic section (fig. 54). Two end members are recognized in the quartz breccia unit, on the basis of matrix mineralogy: (1) quartz-sulfide, and (2) montmorillonite-hematite-opal.

The matrix of the quartz-sulfide end member is dark grey and contains cristobalite, chalcedonic quartz, and as much as 10 percent disseminated, extremely fine grained sulfides, dominantly pyrite and minor amounts of chalcopryite, bravoite, and cobaltite. The breccia clasts are of red to pale-pink microcrystalline quartz with disseminated hematite.

The quartz-sulfide breccia grades laterally away from the center of the deposit to montmorillonite-hematite-opal breccia. The difference between these two breccia types is that the matrix of the second type is composed of montmorillonite, hematite, and opal instead of quartz and sulfides. Clasts of the montmorillonite-hematite-opal breccia can be of quartz-hematite-pyrite, opaline material, or andesite.

The talus deposits grade into the quartz breccia unit. The talus also contains clasts of andesite, opal, and quartz-hematite-pyrite in a loose silty-sandy matrix.

Quaternary colluvium overlies lateral stratigraphic equivalents of the mineralized Pliocene deposits at Borealis. The colluvium contains clasts of andesite and granodiorite from the highlands in the Wassuk Range, and altered Miocene and Pliocene clasts

from the Borealis deposit and surrounding areas of hydrothermal alteration.

Structure

The Borealis deposit apparently occurs at the intersection of three nearly vertical but poorly exposed fault systems: (1) A northeast-trending shear zone, known locally as the Borealis trend, identified by outcrop and drilling data; (2) an east-west-trending set of shears, found by drilling and trenching; and (3) a north-south-trending normal fault, down on the west side, inferred from geophysical (electromagnetic and magnetic) and drilling data. The Borealis trend is a 5-km-long series of silicified and brecciated outcrops, trending approximately N. 50° E. The ore body itself, and the quartz breccia outcrops immediately east of the postulated north-southerly trending fault, constitute evidence for the Borealis trend in the mine area. The east-westerly trending shears, as identified in drill holes and a single trench, contain near-vertical quartz-hematite (after pyrite) breccias carrying anomalous gold.

Alteration

Alteration at the Borealis deposit includes a wide range of silicification and argillization. Silicification ranges from opal to quartz, and argillization from incipient alteration defined by montmorillonite to intense alteration defined by kaolinite-alunite.

The upper parts of the Miocene andesitic section were silicified and argillized by early extreme acid leaching. Remnant porphyritic textures are visible in strongly silicified, acid-leached rocks.

Acid leaching of the andesitic section and overlying tuffaceous sedimentary rocks produced an opal-cristobalite assemblage, locally referred to as sponge rock because of its open texture. This alteration is a near-surface phenomenon and grades with depth into an argillic-alteration assemblage defined by

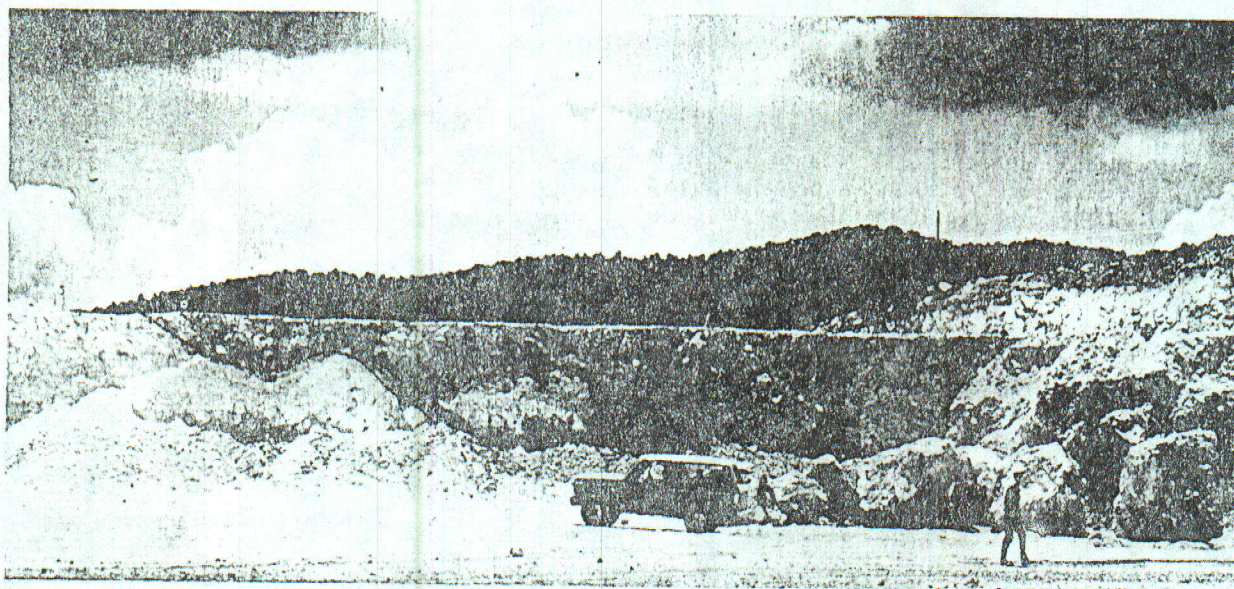


Figure 54. Local unconformity (dashed line) separating earlier barren spring-vent deposits (light colored) from the later quartz breccia in the Borealis pit. View eastward. Photograph taken in 1982.

kaolinite and alunite. The contacts between the sponge rock and kaolinite-alunite alteration vary extremely and range from vertical to horizontal and from sharp to gradational.

Silicification has affected all the rock types; however, it is best characterized within the quartz breccia and spring-vent deposits. The quartz breccia unit is cemented by opal or chalcedonic quartz. Likewise, opal and chalcedony characterize the spring-vent deposits where both the tuffaceous sedimentary rocks and underlying andesite are intensely silicified.

The talus deposit is the least altered of the premineral and synmineral units. The matrix of the sedimentary breccia is locally altered to montmorillonite and hematite, with or without opal lining the insides of small vugs. This alteration is marginal and gradational into central masses of quartz-sulfide breccia.

Mineralization

Two types of ore occur at Borealis: (1) spring vent and (2) quartz breccia. Both ore types are characterized by diverse textures and alteration assemblages.

The spring-vent ores consist of sub-micron- and micron-size gold in combination with jarosite, alunite, barite, hematite, and sulfides of undetermined mineralogy. The yellow and brown oxides and gray sulfides are unconsolidated fine-grained bedded precipitates. Minor amounts of silt- to pebble-size detrital quartz and rock fragments are mixed with chemical precipitates in the spring-vent ores.

Most individual spring-vent-ore bodies are lenticular and range from 3 to 15 m in width, from 3 to 30 m in length, and from 0.15 to 3 m in thickness. Figures 55 and 56 show reconstructions of the spring-vent-ore bodies, developed from blasthole assays. Although these reconstructions ignore the true individual thicknesses of interleaved and superimposed spring-vent lenses, the end result documents the vertical stacking and alignment of the spring-vent-ore bodies over several bench levels in the pit.

The quartz breccia ores, like the spring-vent ores, consist of micron-size gold associated with oxides and minor sulfides in a siliceous to argillaceous matrix. Reflected-light microscopy of heavy-mineral separates from quartz-sulfide ores reveal that the largest gold particles are 25 μm ; however, much of the gold is suspected to be smaller than 2 μm . Sulfides associated with the gold include pyrite, chalcopyrite, bravoite, and cobaltite.

Many of the highest grades of quartz-sulfide breccia contain a hydrothermal overprint of vuggy sugary quartz, crystalline barite, leucoxene, and fine hematite. Lower grades of oxidized quartz-sulfide breccia contain neither the vuggy quartz nor the oxides but, instead, are partially to pervasively oxidized, with little textural change.

The ore body within the quartz breccia unit is an east-northeast-elongate lens. Ore grades within this lens are consistent, with only a few barren internal zones. Lateral contacts of the ore body are gradational

to fairly sharp, whereas the higher grades of the quartz-sulfide breccia pass into lower grades of montmorillonite-hematite-opal breccia. The upper ore-body boundaries are at the base of a thin (1.5-4.5 m thick) leached zone, unless covered by unmineralized sedimentary breccia.

Age of mineralization

The age of the Borealis deposit is bracketed by K-Ar ages on alunite and andesite. F. J. Kleinhampl and M. L. Silberman (written commun., 1980) obtained an age of 4.0 ± 0.5 m.y. on alunite from the acid-leached zone, and R. F. Reid (written commun., 1982) obtained an age of 7.0 ± 0.5 m.y. on hornblende in andesite from the Miocene section. This hornblende age is a maximum for the hydrothermal system because the andesitic section is altered, whereas the alunite age presumably represents the age of acidic alteration during boiling of hydrothermal solutions in the near-surface environment.

DISCUSSION

The genesis of the Borealis deposit has been considered in terms of the Steamboat Springs geothermal system (Schoen and others, 1974; White, 1981). The basis for this comparison is the similarity between the alteration types at Borealis and Steamboat Springs. Spring-vent-ore bodies are aligned in a northeastward direction, to the north-southerly alignment of spring vents at Steamboat Springs. This alignment at Borealis reflects control by underlying fluid conduits, defined by northeast-striking structures.

The spring vent deposits probably were precipitated just below the air-water interface in a subaerial hot-spring environment. Bedded oxides commonly overlie the sulfides in the spring-vent ores, but interbedding of the oxides and sulfides in some places suggests hypogene oxide formation, which would infer that the Eh of the precipitating fluid was partly responsible for oxide formation. A periodic variation in the proportionate mixing of hydrothermal and paleosurface waters, or an occasional waning of hydrothermal-fluid flow, may have been responsible for the indicated Eh change. Hypogene oxide precipitation has a bolder, clearer counterpart in the ores of the quartz breccia unit.

The quartz breccia unit was formed by explosive, repetitive hydrothermal activity. The resulting breccia was deposited contemporaneously with the talus deposits. Both units were subsequently altered by continued discharge of the geothermal system. The texture and mineralogy of the clasts indicate strong quartz recrystallization and oxidation during each hydrothermal cycle before the introduction of matrix sulfides under reducing conditions. Clast boundaries in these two units are sharp. The oxidized quartz-hematite clasts, the later quartz-sulfide matrix, and the still-later oxide overprint indicate wide and, possibly, cyclic fluctuations in the Eh (and pH?) of the hydrothermal fluids which mineralized the quartz breccia unit. These redox fluctuations may reflect variations in the chemistry and (or) volume of rising

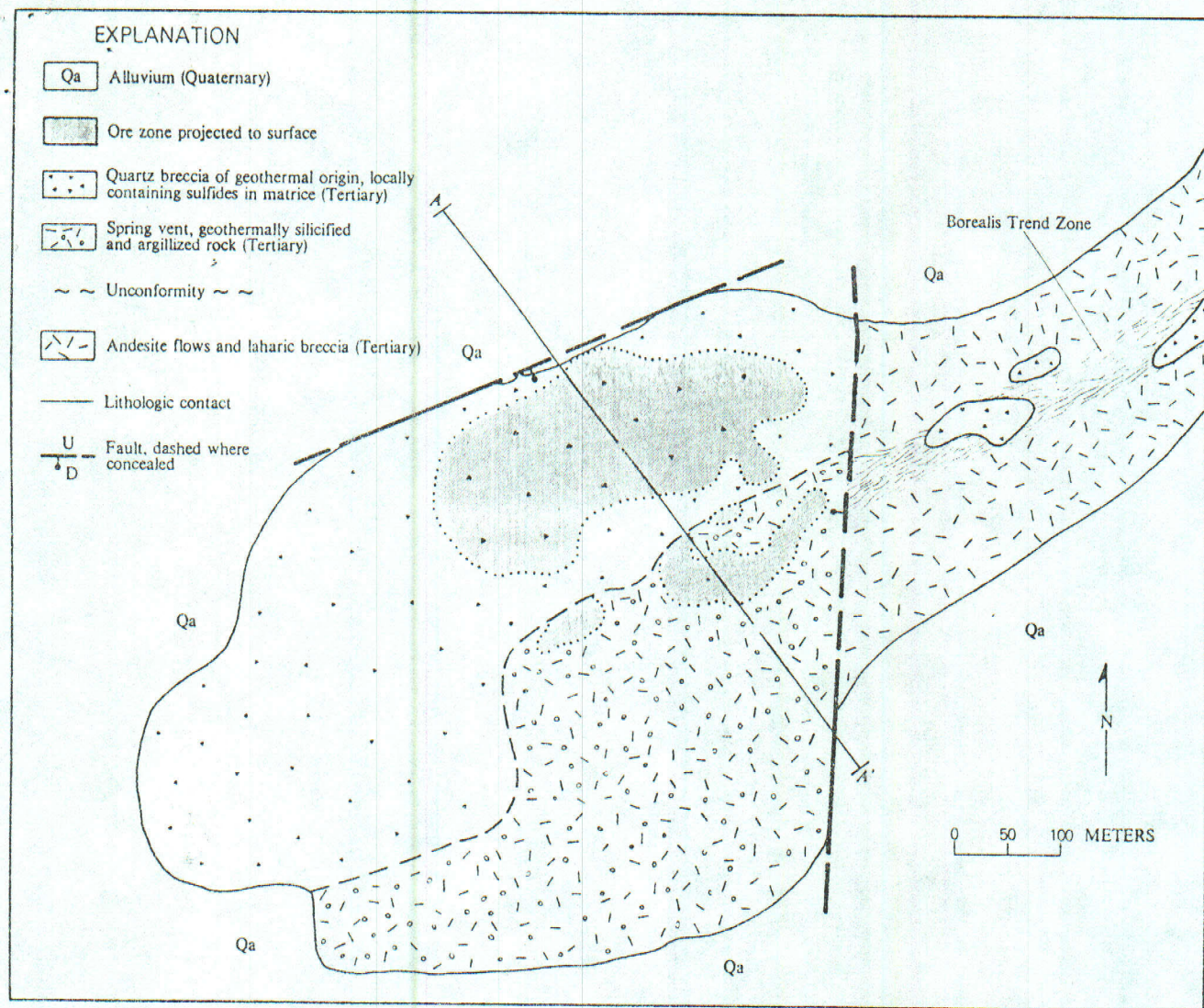


Figure 55. Generalized sketch of geologic relations at the Borealis minesite.

hydrothermal fluids during deposition of the quartz breccia unit.

The acid-leached sponge rock and the less intensely leached kaolinite-alunite alteration assemblages in the spring-vent unit could have formed in a subaerial to vadose environment. The genetic environment of sponge rock and similar acid-leached alteration types at Steamboat Springs, Nev., was described by Schoen and others (1974). Hydrothermal fluids at Steamboat Springs are venting beneath a subaerial surface. Vapors with a pH as high as 2, derived from boiling fluids, condense on vent walls and nearby rock or soil surfaces. These acidic condensates percolate into the substrate and downward to the water table, where they leach away most major components except silica, zirconium, and titanium. In extreme acid leaching above the water table, even silica is mobilized for short distances and redeposited as opal. A similar mechanism is envisioned to have occurred at Borealis and formed the sponge rock.

Precious metals and sulfides precipitate from spring waters at Steamboat Springs. Similarly, the

spring-vent ores at Borealis precipitated from geothermal water near the top of the paleowater table. A rising water table, possibly aided by the gradually sinking northeast margin of the Fletcher basin, created the vertical stacking of spring-vent-ore bodies at Borealis. Some of the lower spring-vent-ore bodies may have formed in leached zones within the upper few meters of andesite. Later, the higher spring-vent-ores developed in overlying hot-spring-associated breccias and tuffaceous sedimentary rocks.

During the last stages of spring-vent activity, a series of normal dislocations may have existed along the north-southerly trending fault on the present east margin of the deposit, and along the northeasterly Borealis trend. These dislocations created a local depression on the northwest side of the present acid-leached spring-vent edifice (figs. 55, 56). Taluslike sedimentary breccia immediately began to accumulate, and hydrothermal fluids (previously venting in the subaerial and vadose spring-vent environment) were diverted to conduits beneath the accumulating talus. Spring-vent activity or, at least, the associated

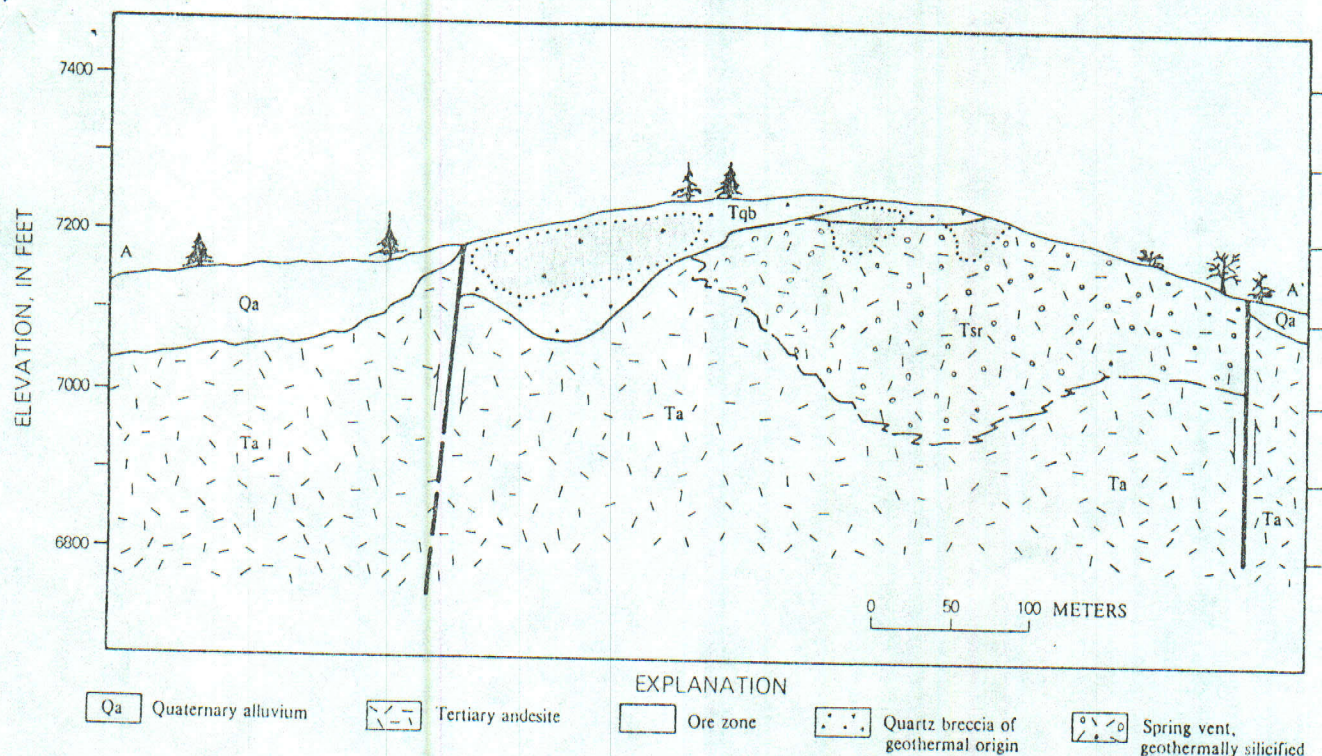


Figure 56. Schematic cross section of the Borealis minesite.

subaerial acid leaching terminated approximately contemporaneously.

Fluids venting upward into the sedimentary and hydrothermal breccias silicified and mineralized both the finer grained matrix and constituent clasts. However, acid leaching of the spring-vent type did not affect the quartz breccia unit, probably because the vents and overlying sedimentary breccia were below the local water table.

A cyclic explosive/passive aspect to hydrothermal venting is apparent in the development of the quartz breccia ore body. The explosiveness of the mineralizing fluids is attested to by: (1) the craterlike walls at the base of the quartz breccia ores; (2) vertical collapsed pipes, at least 3 m in diameter, cutting argillically altered andesite below the pre-quartz breccia unconformity; and (3) explosive fluid-streaming textures in some of the highest grades of quartz-sulfide breccia ores. Passive, waning stage(?), more highly oxidizing hydrothermal fluids produced the quartz-barite-hematite assemblages in the highest grade quartz-sulfide breccia ore.

Borealis seems to be part of the fossil surficial vent area of a structurally controlled epithermal system cutting Tertiary volcanic rocks. The cyclicity of paleosurface ores at Borealis may be a manifestation of the same mechanisms that cause cyclicity in vein mineralogy, as observed in other, more deeply eroded epithermal deposits.

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